LIMITED CIRCULATION

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The Calculation of Wet Bulb Temperatures

by M J Lee

1. Introduction

Most of the time the atmosphere is unsaturated, and can therefore absorb some more water vapour. The extra amount of water vapour the air can take up before becoming saturated is quantified as the difference between the saturation vapour pressure and the ambient vapour pressure, that is the vapour pressure deficit.

The ability of the atmosphere to take up water vapour is also regulated by the temperature; the higher the temperature, the higher the vapour pressures that the air can sustain before becoming saturated. In the majority of conditions, evaporation takes place approximately isothermally, because heat losses due to latent heat are compensated for by sensible heat fluxes and radiation. Consequently vapour pressure deficits can be calculated using the saturation vapour pressure at the dry bulb temperature.

Occasionally conditions arise where there is very little, if any external heat to maintain the temperature as evaporation proceeds, so that conditions are adiabatic. Therefore the air temperature falls, which reduces the air's ability to take up further moisture before becoming saturated. Confined spaces, such as inside unheated buildings, will display nearly adiabatic cooling during evaporation, and the air will become saturated at the wet bulb instead of the dry bulb temperature. Consequently vapour pressure deficits in such conditions must be calculated using the saturation vapour pressure at wet bulb temperature.

Clearly, in order to calculate vapour pressure deficits in adiabatic conditions, a knowledge of the wet bulb temperature is required. However, this quantity although measured is not often recorded, but the dry bulb temperature, relative humidity or vapour pressure, and pressure usually are recorded.

This paper describes a computer program for calculating wet bulb temperatures.

2. Theory

Given values of temperature, relatively humidity and pressure, two equations can be conveniently solved simultaneously to produce a value for the wet bulb temperature. They are as follows:-

$$e_{sw} = \exp\left(M_v L / R^* \left(\frac{1}{273} - \frac{1}{T_w}\right)\right) \times 6.11 \qquad (1)$$

$$e_{sw} = e + \frac{M_d c_p}{M_v L} p (T - T_w) \qquad (2)$$

Where e_{sw} = saturation vapour pressure at the wet bulb temperature (mb).

L = latent heat of vapourisation
$= 2.499 \times 10^6 - 2.37 \times 10^3 (T_w - 273)$ J kg^{-1}

R^* = universal gas constant = 8.314×10^3 J kmol^{-1} K^{-1}

T_w = wet bulb temperature (K)

T = dry bulb temperature (K)

p = air pressure (mb)

e = vapour pressure (mb)

c_p = specific heat of air at constant pressure
$= 1.01 \times 10^3$ J kg^{-1} K^{-1}

M_v = molecular weight of water vapour = 18 kg kmol^{-1}

M_d = molecular weight of air = 29 kg kmol^{-1}

Analytically these equations would be very difficult to solve, but numerically on the computer, test values of T_w can be used in both equations until they yield identical values of e_{sw}.

In reality free evaporation will not occur from the surface unless air is continuously advected across it sufficiently fast. In conditions of free evaporation the wet bulb temperature will be lower than in those conditions when evaporation cannot occur so freely because moist air is not being removed rapidly from the evaporating surface. The variation in wet bulb temperature due to the above effect is accommodated for by altering the Psychrometric constant (A), which is defined as $M_d\ c_p\ P/M_v L$ in equation 2.

For advective wind speeds of about 3 ms^{-1} (corresponding to a Psychrometer) A = 6.59×10^{-4} p mb K^{-1}; for advective wind speeds below about 3 ms^{-1} (corresponding to a Stevenson Screen) A is usually put equal to 7.89×10^{-4} p mb K^{-1}.

3. Computer Program

A Fortran listing of the subroutine used to calculate T_w is given in Appendix 1, and is stored as UWETBLB on MO8.SRCELIB and MO8.OBJLIB. The T_w values are evaluated to the nearest 0.1°C, between 0°C and 40°C. If T_w is less than 0°C the default value of -32768.0 is returned.

The argument list to be used is as follows:-

1. Temperature of the dry bulb in degrees C.

2. Atmospheric pressure in mb.

3. Vapour pressure in mb.

4. Wet bulb temperature in degrees C.

5. 1. If wet bulb temperature from free evaporation (Psychrometer) is required.

   2. If wet bulb temperature for low advective air flows (Stevenson Screen) is required.

Arguments 1-4 are 4 byte real and argument 5 is 4 byte integer.

Any comments or suggestions on this paper should be referred to the author.

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APPENDIX 1

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C SUBROUTINE FOR CALCULATING WET BULB TEMPERATURES
C DEVELOPED BY M.J.LEE DECEMBER 1983
      SUBROUTINE WETBLB(TEMP,PRES,VP,TW,IVENT)
C ARGUMENT LIST:- TEMP=TEMPERATURE
C                 PRES=PRESSURE
C                   VP=VAPOUR PRESSURE
C                   TW=WET BULB TEMPERATURE
C                IVENT=1 FOR PSYCHROMETER
C                      2 FOR STEVENSON SCREEN
      DIMENSION VENT(2)
      VENT(1)=0.000659
      VENT(2)=0.000789
      DIFKP=1000.
C CONVERT TEMPERATURE TO ABSOLUTE
      T=TEMP+273.
C LOOP FOR TRIAL TW VALUES
      DO 10 IT=0,400
      TGES=273.+FLOAT(IT)*0.1
C CALCULATE LATENT HEAT OF VAPOURIZATION
      XLV=2499000.-2370.*(TGES-273.)
      CONST=(18.016*XLV)/8313.6
C CALCULATE SATURATION VAPOUR PRESSURES
      EST1=EXP(CONST*(0.003663-(1./TGES)))*6.11
      EST2=VP+(T-TGES)*PRES*VENT(IVENT)
C FIND THE SMALLEST DIFFERENCE
      DIF=ABS(EST1-EST2)
      IF (DIF.GT.DIFKP) GOTO 20
      DIFKP=DIF
   10 CONTINUE
      WRITE(6,1)
    1 FORMAT(' TW IS GREATER THAN 40C')
      STOP
C CONVERT TW TO DEGREES CENTIGRADE
   20 TW=TGES-273.1
      IF (TW.LE.0.0) TW=-32768.
      RETURN
      END
```